EXIT89 - AN EVACUATION MODEL FOR HIGH-RISE BUILDINGS - RECENT ENHANCEMENTS AND EXAMPLE APPLICATIONS

by

Rita F. Fahy
Fire Analysis and Research Division
National Fire Protection Association
1 Batterymarch Park
Quincy, MA 02269-9101

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Quincy, Massachusetts 02269-9101 U.S.A.

Background

The origin and basic features of EXIT89 have been described in previous papers. [1] This paper will concentrate on a brief discussion of the framework of the model, a description of recent enhancements made to the model and will present example applications of the model that illustrate some of its features.

EXIT89 was designed to model the evacuation of a large building with the capability of tracking each occupant individually. The output of this model, in combination with a fire and smoke movement model using the same building layout, can be used to predict the effects of cumulative exposure to the toxic environment present in a structure fire.

In EXIT89 behaviors can be implicitly modeled to some degree by using some of the features of the model. Delays in beginning evacuation are common in real situations, where occupants may assume that they are hearing another false alarm, or they may hesitate to respond to cues, including smoke, because no one else is reacting. Delays can also occur as a result of activities the occupants engage in before beginning to exit the building. These delays can include investigating the source of the alarm or smoke, securing files, gathering personal belongings, and notifying others of the situation. These delays can be modeled by setting a delay for each location in a building and having all occupants at the location wait that amount of time before beginning to leave.

Data from real evacuations have also shown that delays occur during the course of exiting the building as people seek information, gather belongings, alert others, fight the fire, etc. [2] As a step toward simulating that occurrence, delays can be randomly assigned to any specified proportion of the occupants of the building. Observations of exit choice during evacuations indicate that occupants of a building will often take the same route out of a building that they took coming in. [3] EXIT89 allows the user to model this behavior, rather than have all occupants follow calculated shortest routes out of the building.

The model has recently been modified to simulate the evacuation of disabled occupants by reducing the walking speeds of selected occupants.

Program Description

EXIT89 requires as input a network description of the building, geometrical data for each room and for openings between rooms, the number of occupants located at each node throughout the building, and smoke data if the effect of smoke blockages is to be considered. The user is allowed to select among several options, including whether the occupants of the building will follow shortest paths out of the building or will use familiar routes; whether smoke data, if any, comes from a fire and smoke model or will be input as blockages by the user; whether there are any delays in evacuation throughout the building; whether there are any additional delays in evacuation among the occupants of the building and, if so, what percentage of the occupants will delay and what are the minimum and maximum delay times; and whether any of the occupants are disabled and if so, at what percentage of "normal" speed will each person travel.

The following is a brief overview of the model. It either calculates the shortest route from each building location to a location of safety (usually outside) or sets user-defined routes through the building. It moves people along the calculated or defined routes until a location is blocked by smoke. Affected exit routes are recalculated and people movement continues until the next blockage occurs or until everyone who can escape has reached the outside.

Evacuation can begin for all occupants at time 0 or can be delayed. Additional delays over a specified range of time can be randomly assigned to occupants. Smoke data can be used to predict when the activation of a smoke detector would occur and evacuation will begin then or after some user-defined delay beyond that time. The program is written in FORTRAN and currently running in mainframe and PC versions.

Using The Model

EXIT89 can be used in two different ways. The user can input the names of nodes that become blocked by smoke and the time those blockages occur. Or, the user can take the smoke data output from CFAST as input to the model. CFAST will calculate and write to a disk file the smoke levels of the hot upper layer at each node at each time interval and the height from the floor of the cooler lower layer. In the first version, evacuation begins simultaneously throughout the building at time 0, plus any delay time specified at nodes by the user or randomly assigned by the model. In the second version, evacuation begins throughout the building when the smoke level reaches that defined for smoke detector activation, plus any delay time specified at nodes by the user or randomly assigned by the model. By using the first version and not specifying any blockages, the user can model evacuation of a building with no fire occurring.

The program will print out the movement of each occupant from node to node. It also records the location of each occupant at each time interval so that the output can be used as input to a model such as TENAB, the tenability component of HAZARD I. [4] TENAB will calculate the hazards to which each occupant was exposed using CFAST output for combustion products and will determine when incapacitation or death occurs. The user can suppress this output and have the model only print out a summary showing floor clearing times, stairway clearing times and last time each exit was used and how many people used each exit.

Calculating Walking Speeds

EXIT89 uses walking speeds calculated as a function of density based on formulas from Predtechenskii and Milinskii. [5] This is described fully in previous papers. Their model established an optimal density of 0.92. Tables of velocities by density were given for normal, emergency and comfortable movement along horizontal paths, through openings and on stairs. EXIT89 currently incorporates the velocities for normal and emergency movement.

Predtechenskii and Milinskii's work used body sizes calculated from the measurements of Soviet subjects. The area of horizontal projection of a person used in these calculations is 0.113 m^2 (1.22 ft^2) -- the mean dimensions of an adult in mid-season street dress. Subsequent work by Ezel Kendik using Austrian subjects found significant differences in the results. [6] The value of 0.113 m^2 described above compares to the Austrian result for subjects between the ages of 10 and 15 years without coats. The value for Austrian subjects between ages 15 and 30 wearing coats was 0.1862 m^2 and without coats was 0.1458 m^2. The value for adults over age 30 without coats was 0.1740 m^2.

A table of mean body dimensions representative of U.S. male and female workers between 18 and 45 years of age was obtained from *Occupational Safety and Health in Business and Industry*. Based on this data, an "American" value for horizontal projection of a person of 0.0906 m^2 was calculated, far smaller than that calculated for Soviet or Austrian subjects. The choice among the three sets of data is an input option set by the user.

Moving The Occupants

The initial routes throughout the building are calculated by the model (if the shortest route option is selected) or determined by the user before any smoke data is read in. For the first version of the model, where the user enters the location and time of smoke blockages, notification to begin evacuation occurs at time 0. For the second version, the model reads in the smoke data and determines where and when blockages would occur and when smoke detector activation would occur and evacuation would begin.

The model begins by calculating, based on the initial distribution of occupants, how long it would take to travel from each occupied node to its connected node. Then for each occupant, it looks at how long that occupant has been at that node and how long it takes to traverse the arc. If the occupant has been waiting long enough to traverse the arc, the occupant is moved to the next node, and the waiting time at that node is set to 0. Waiting times are actually portions of the arc traversal times. If there are still occupants in the building, the model recalculates time to traverse arcs based on the updated densities at nodes.

The sequence is repeated until the time is reached when a node is blocked by smoke. At that point, the affected node is removed from the network, any occupants at that node are counted as trapped and shortest routes are recalculated for the affected floor (or floors if the node is in a stairway). People movement is then resumed until the next blockage or until everyone is either out of the building or trapped.

Queuing is handled by the decreased walking speeds that result from increased densities as more occupants move into a room or stair. The program does not currently allow occupants to select less crowded routes; they simply join the queue at nodes along the shortest route.

Example Applications

A series of evacuations conducted by the University of Ulster tested the effect of disabled persons on occupant flow in mixed ability populations. [7] One of these evacuations took place in a hotel with a daytime scenario. This is the evacuation for which EXIT89 was run for these examples.

The hotel wing used for the evacuation was a two-story structure with exit stairs at both ends and another stairwell in the center. One of the end stairs was made unavailable for the evacuation. Several of the occupants taking part in the evacuation were disabled. They included users of wheelchairs, canes and walkers.

The initial locations of the occupants for each of the evacuation exercises were provided on floor plans. Also available were the length of time it took occupants to leave their rooms and their time to leave the building. The location of cameras through the building allowed researchers to determine the duration and causes of additional delays during evacuation.

In all of the actual evacuations, disabled occupants were present; however, it was found that they did not adversely impact the movement of the non-disabled evacuees.

Example 1 - Randomly Distributed Delay Times

In the first daytime scenario, estimated delays in evacuating bedrooms ranged from one to 30 seconds. In addition, 14 out of 27 able-bodied occupants observed by cameras delayed at some point in the corridors during their evacuation. The duration and reasons for these delays were detailed in the report. The reasons included, among others, stopping to read a notice on the foyer door (one to two second delay), holding doors open for wheelchair users (nine to 13 second delay), calling on friends (up to 30 second delay) and traveling in the opposite direction of designated escape route (up to nine second delay). Among the 22 non-disabled occupants observed by cameras in this evacuation, the times to reach the exit ranged from 16.6 to 60.0 seconds with a mean time of 37.1 seconds.

The first run of this evacuation used reported and estimated delay times in the rooms for these occupants and resulted in evacuation times that ranged from 23.1 to 60.1 seconds with a mean time of 39.5 seconds. A second run of this evacuation added random delays of one to 30 seconds to half of the occupants. In this case, the predicted evacuation times ranged from 23.1 to 79.1 seconds with a mean time of 45.8 seconds. A closer look at the movement of the occupants showed that many of the occupants actually reached the exit sooner because the delays reduced congestion in the corridors and allowed them freer and more rapid movement. Since most of the reported delays during evacuation actually lasted less than 10 seconds, the example was run a third time with random delays of one to 10 seconds distributed among half the occupants. This resulted in predicted evacuation times that ranged from 23.1 to 65.8 seconds with a mean time of 41.8 seconds.

<u>Example 2 - Adding Disabled Occupants</u>

Building on the final results of Example 1, four disabled occupants were added to the modeled population. There were actually five disabled occupants in the real evacuation, but travel speed was not available for one of the wheelchair occupants. Two wheelchair occupants traveled at speeds close to the average for able-bodied occupants (1.15 m/s vs. 1.52 m/s). The other two disabled occupants were a wheelchair user who traveled at about one-eighth of the average speed of the able-bodied occupants, as a result of impedance from a walker user who traveled at about one-fifteenth of the average speed of the able-bodied occupants.

The model was rerun with these four disabled occupants added. As was observed in the actual evacuation, there was no effect on the travel times of the able-bodied evacuees. The travel times observed in the actual evacuation for these four people were 51.0 seconds, 56.9 seconds, 174.0 seconds and 222.0 seconds. The times estimated for them in the model were 58.0 seconds, 61.7 seconds, 182.3 seconds and 295.4 seconds, respectively.

Conclusion

The model in its current form does not include explicit behavioral considerations but it does allow behaviors to be handled implicitly by incorporating time to perform investigation activities or to alert others before evacuating in the delay times that the user specifies for the occupants of each node. In addition to specifying delay times for each location, the user can also have the computer randomly assign additional delays to some percentage of the individuals throughout the building. In this same way, another behavior that can be dealt with implicitly is the tendency of able-bodied adults in the presence of other able-bodied adults to ignore early warnings of the presence of a fire.

EXIT89 allows the user to model the frequently observed tendency of occupants to follow the route out of the building that they are most familiar with, not the shortest paths out of building which often would involve the use of emergency exits. These familiar paths defined by the user will remain in place until a location on that floor becomes blocked by smoke and the routes on that floor need to be recalculated using the shortest route algorithm.

Walking speeds are calculated as a function of densities and are based on tables of values from Predtechenskii and Milinskii. The model does not yet simulate crawling through smoky rooms by reducing walking speeds, or reversing direction where possible to use a less smoky, though longer escape route. Disabled occupants can now be modeled using reduced walking speeds.

One of the program's inputs is the capacity of nodes. The reason for including this value was to allow evacuees to avoid nodes that were already crowded if alternate routes are available. This would prevent occupants from queuing at one stairway while the other section or sections of the floor emptied into less busy stairways. Refinements of the program to define and possibly limit the range of a smoke detector also need to be added to the model.

Future plans for the model include documenting from available literature travel speeds and the delay times that can be used for occupants to begin evacuation and for delays during evacuation. These travel speeds and delay times may be occupancy-specific. Testing of the model using data from actual emergency and non-emergency evacuations will also continue.

Acknowledgments

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